Fisheries and Oceans Canada | Pêches et Océans Canada
Science | Sciences

CSAS | **SCCS**

Canadian Science Advisory Secretariat | **Secrétariat canadien de consultation scientifique**

Research Document 2002/054 | **Document de recherche 2002/054**

Not to be cited without permission of the authors * | Ne pas citer sans autorisation des auteurs *

Estimated Consumption of Atlantic Cod (*Gadus morhua)* and some Other Prey by Grey seals (*Halichoerus grypus*) and Harp seals (*Phoca groenlandica*), in the Southern Gulf of St. Lawrence (NAFO Division 4T)

by

M. O. Hammill [1] and G.B. Stenson[2]

[1]Maurice Lamontagne Institute
P.O. Box 1000, Mont-Joli, Quebec, G5H 3Z

[2]Northwest Atlantic Fisheries Centre
P.O. Box 5667, St John's, Newfoundland, A1C 5X1

* This series documents the scientific basis for the evaluation of fisheries resources in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

* La présente série documente les bases scientifiques des évaluations des ressources halieutiques du Canada. Elle traite des problèmes courants selon les échéanciers dictés. Les documents qu'elle contient ne doivent pas être considérés comme des énoncés définitifs sur les sujets traités, mais plutôt comme des rapports d'étape sur les études en cours.

Research documents are produced in the official language in which they are provided to the Secretariat.

Les documents de recherche sont publiés dans la langue officielle utilisée dans le manuscrit envoyé au Secrétariat.

This document is available on the Internet at: http://www.dfo-mpo.gc.ca/csas/

Ce document est disponible sur l'Internet à:

ISSN 1480-4883
© Her Majesty the Queen in Right of Canada, 2002
© Sa majesté la Reine, Chef du Canada, 2002

Canada

Abstract

Consumption of Atlantic cod, Atlantic herring and some other species by seals in the southern Gulf of St. Lawrence (NAFO Division 4T) was estimated for the period 1975-2001. Estimates were obtained by combining information on abundance, energy requirements, diet composition and the distribution of animals. Consumption of Atlantic cod, and Atlantic Herring by grey seals in NAFO Division 4T is in the order of 5,700 t (SD=3,400), and 4,800 t (SD=2,500) respectively. Harp seal consumption based on diet samples from the Magdalen Islands and the St. Lawrence estuary is around 60 tonnes (SD=180), but sampling is limited to the winter months when cod are absent from the Gulf. Cod consumption by harp seals could be much higher but estimates are based on a key assumption that diet composition is similar to harp seal diet composition along the west coast of Newfoundland. Current estimates differ from earlier studies by attempting to incorporate variability in population estimates, seal distribution, and diet composition in our model. Harp seals appear to feed primarily on cod less than 31 cm in length, but variability in prey length in this study and elsewhere have been observed. Better diet sampling and information on the spatial distribution of seals will improve estimates of consumption.

Résumé

La consommation de morue, de hareng et d'autres espèces par les phoques dans le sud du golfe du Saint-Laurent a été estimée pour la période de 1975-2001. Les estimations ont été obtenues en combinant l'information sur l'abondance, les besoins énergétiques, la composition de la diète et la distribution des animaux. Les consommations de morue et de hareng par les phoques gris dans la division 4T de l'OPANO sont respectivement de l'ordre de 5 700 t (écart-type = 3 400) et de 4 800 (écart-type = 2 500). La consommation par les phoques du Groenland, basée sur des échantillons de diète provenant des Îles-de-la-Madeleine et de l'estuaire du Saint-Laurent, est environ 60 tonnes (écart-type = 180), mais l'échantillonnage est limité aux mois d'hiver lorsque la morue est absente du golfe. La consommation de morue par les phoques du Groenland pourrait être beaucoup plus importante, mais les estimations reposent sur le postulat que la composition de la diète est similaire à la diète des phoques du Groenland le long de la côte ouest de Terre-Neuve. Les estimations actuelles diffèrent des études antérieures parce que de la variabilité dans les estimations de population, dans la distribution des phoques et dans la composition de la diète ont été introduites dans notre modèle. Les phoques du Groenland semblent se nourrir principalement de morue de moins de 31 cm de longueur, mais de la variabilité dans la longueur des proies a été observée dans cette étude comme ailleurs. Un meilleur échantillonnage pour la diète et une meilleure information sur la distribution spatiale des phoques pourra améliorer les estimations de consommation.

Introduction

Marine mammals, because of their large size and abundance, may have an important influence on the structure and function of many marine ecosystems, but empirical data is lacking to support this hypothesis (Bowen, 1997). One obvious impact is that large quantities of prey are consumed by marine mammals, to the detriment of commercial fisheries. Evaluating the magnitude of this consumption requires information on population size, energetic requirements, diet composition, size classes and energy density of the prey, as well as the distribution of marine mammal feeding effort (Harwood and Croxall, 1988; Harwood, 1992). Hammill and Stenson (2000) provided estimates of grey seals (*Halichoerus grypus*), harbour seals (*Phoca vitulina*), harp seals (*Phoca groenlandica*) and hooded seals (*Cystophora cristata*) throughout Atlantic Canada during the period 1990-1996. Harp and grey seals were identified as the two most important pinniped predators in the Gulf of St. Lawrence owing to their abundance in this area. However, in that study diet information for grey seals in NAFO Division 4T was limited. Instead, grey seal diets from NAFO Divisions and sub-Divisions surrounding 4T (eg 4S, 4VS, 4W) were combined to derive a 4T diet. In the case of harp seals, diet data were also limited and it was assumed that feeding occurred primarily to the north of 4T (Hammill and Stenson 2000). Since 1996 more information has been obtained concerning grey seal diet composition in 4T. At the same time other changes have occurred as well. Beginning in 1997, changes in estimates of pup production also indicate that the Gulf grey seal population may no longer be increasing and could in fact be decreasing. Here we examine grey seal prey consumption in 4T. We present estimates of harp seal consumption in this area using methods similar to those developed by Hammill and Stenson (2000) and we also examine the scenario of what cod consumption by harp seals could be, if diet was similar to that observed in 4R.

Materials and Methods

Estimates of prey consumption were developed by modelling changes in population size, energy requirements, diet composition and changes in distribution for harp and grey seals.

Estimates of grey and harp seal pup production, and reproduction rates were incorporated into a population model (grey seals : Mohn and Bowen 1996; harp seals : Healey and Stenson 2000) to estimate total population size and the change in numbers over time. Estimates of grey seal population size were modified slightly from Mohn and Bowen (1996). In their study, male grey seals were assumed to have a much higher mortality rate than female grey seals. However, Mansfield and Beck (1977) and more recently (Manske *et al.* 2002) have suggested that there is little difference in mortality rates between mature male and female grey seals, at least prior to 30 years of age. Therefore we assumed that there was no difference in mortality between males and females $\leq$30 years old.

Energy requirements were assumed to be constant throughout the year. Age-specific energy requirements were calculated using :

$$GEI_i = GP_i * (AF*293 *BM_i^{0.75}) /ME$$

where GEI_i is daily gross energy intake (kjoules/day) at age i, and GP is the additional energy required by young seals (< age 6). GP_i was set at 1.8, 1.6, 1.4, 1.3, 1.1, 1.1, and 1.0 for animals aged 0, 1, 2, 3, 4, 5, and ≥6 yrs respectively (Olesiuk, 1993). The activity factor (AF) was assumed to be 2 (Worthy, 1990) to approximate the average daily energy requirements as a multiple of the basal metabolic rate ($293*BM_i^{0.75}$; Kleiber 1975) where BM_i is body mass at age in kg. The metabolizable energy (ME) was set at 0.83 (Ronald *et al.*, 1984) based on the assumption that seals primarily consume fish. Growth in body mass at age i (BM_i) was modeled using a re-parameterized form of the Gompertz growth curve (Table 1) (Hammill *et al.*, 1995) :

$$BM_i = W_\infty \bullet \left(\frac{W_0}{W_\infty}\right)^{\exp\left[\frac{k_0 \bullet i}{W_0 \ln\left(W_0/W_\infty\right)}\right]}$$

where body mass (BM_i), asymptotic weight W_∞ , and weight at birth (W_0) are in kg, i is age (in years) and k_0 is the rate of growth at birth. Parameters of the growth curves for each species were determined using Proc NLIN (SAS Institute, 1987).

The study region off eastern Canada was divided into the NAFO (North Atlantic Fisheries Organization) scientific and statistical Divisions and Sub-Divisions (Figure 1). The seasonal distribution of each species in each of these areas was estimated from field observations, tag returns, aerial survey observations, historical catch data, anecdotal reports, and satellite telemetry. For harp seals, 20% of the population is assumed to remain in the Arctic. A third of the adult population and 20% of juveniles (ages 0-4 years) enter the Gulf of St. Lawrence on December 1 where they remain until 30 May (Hammill and Stenson 2000). A small proportion of these animals remain in the Gulf year round (1%). The distribution of animals within the Gulf changes throughout the winter (Table 2). The remainder of the population remains off the Newfoundland/Labrador coast (Hammill and Stenson 2000). Grey seals are considered as two groups, a Sable Island herd and a Gulf herd, based on the location of the two largest whelping concentrations of grey seals in Atlantic Canada. Seasonal changes in the distribution of both herds are shown in Table 3. This distribution has been modified slightly from that used in 2001 due to information from satellite transmitters (Table 4).

The proportion of each prey species in the diet was determined by reconstructing the wet weight of prey ingested from stomach samples. Harp seal samples were obtained in the St. Lawrence River estuary and Magdalen Island area (Table 5) (Murie and Lavigne 1991; Beck *et al.* 1993). The harp seal diet sample is very

small. There is also no data available for harp seals in 4VN. We therefore examined what the consumption of harp seals in 4VN could be, using a diet from a sample of 784 animals collected off the west coast of Newfoundland (4R). This sample consists of animals collected near the southwestern tip of Newfoundland, where 4RS cod overwinter and animals that were collected farther north along the west Newfoundland coast. In the 4R assessment this diet was separated into a high cod diet for the southern part of 4R(d) and a low cod diet for the northern part of 4R(abc). Here, we have maintained this separation (Table 6).

Grey seal samples were obtained between 1994 and 2000 from the Magdalen Islands, Miramichi, Northumberland Strait near Amet Island and Charlottetown and Margaree Island on the west side of Cape Breton Island (Table 7). To estimate uncertainty associated with diets, samples were grouped according to location and season (Winter=October-March or Spring =April-September) of collection and simulated data sets of total energy consumed were created using a bootstrapping (i.e. resampling-with-replacement) technique (Table 8) (Resampling Stats Inc., Arlington VA, USA 1999). Each stomach was treated as a unit for resampling purposes. This process was repeated 1000 times to generate estimates of total mass and hence energy, from which proportions contributed by each prey group could be calculated. Visual examination of these distributions suggested that they followed a normal distribution and therefore, means and standard errors were calculated. For grey seals in 4VN, it was assumed that 4T cod were consumed for 2 out of the 3 months in the first Quarter (Jan-March) and during only 1 month in the second Quarter (Apr-June). The 4VN diet was taken from Bowen *et al.* (1993), where cod accounted for about 10% of the diet in terms of energy. The winter diet had a samples size of 16 animals, the summer diet had a sample size of 90 animals.

The amounts of fish consumed by seals were estimated by modeling changes in population size, energy requirements, diet composition and seasonal changes in distribution. Uncertainty in these calculations was estimated by resampling (@Risk, Palisade Corporation, Newfield NY, USA 2000) the numbers at age, growth parameters, proportion of prey in the diet, and the residency period in each area.

Results

The abundance of harp seals has increased over the last three decades from an estimated 2 million animals in the early 1970s to just over 5 million animals in 1999 (Figure 2). In recent years the population has stabilized owing to the high harvests that have occurred since 1997. During winter about 1.2 million harp seals enter the Gulf of St. Lawrence. The proportion in 4T may vary from as low as 35% in May to as many as 70% of the herd in March largely around the Magdalen Islands.

Grey seal abundance has also increased markedly over the last three decades from 26,000 animals in the early 1970's to approximately 325,000 animals in 2001. Survey data are not available for Sable Island since 1997 and it is assumed that

population growth has continued. The Gulf of St. Lawrence whelping herd peaked in 1996, but surveys completed in 1997 and 1999 indicate that it has since declined (Figure 3). Early in the time series most of the NW Atlantic grey seal population was associated with the Gulf of St. Lawrence while the segment known as Sable Island grey seals comprised about 25% of the total population. Since the 1970's, the Sable Island component of the population has increased more rapidly and today Sable Island grey seals account for 82% of the total population today (Figure 3).

The diet composition of grey seals varied considerably between in years. Species such as Sandlance and Winter Flounder varied from being completely absent from the diet to as much as 30% and 80% respectively (Table 7). Some of this variability may be accounted for by the origin of the samples. For example the years with large amounts of Winter Flounder are dominated by samples from Northumberland Strait (Amet Island and Hillsborough Bay). Overall the most important prey items were Winter Flounder followed by Cunner, White Hake and Sandlance . In the bootstrapped sample, Cod accounted for about 6% of the diet (Table 8). In 4VN, the proportion of cod in the diet is 10% (Bowen *et al.* 1993).

Among harp seals, capelin were the most important prey, particularly in the samples from Les Escoumins. In the Magdalen Islands, Yellow-tailed Flounder, Windowpane and invertebrates were the predominant prey. Snow crab has only been found in the samples taken at the Magdalen Islands (Table 5). In the diet from the northern Gulf (4R) (Figure 1), the proportion of cod in the diet varies from a low of 4% during the winter in the northern part of NAFO Division 4R (4Rabc), to a high of 37% in the winter sample from the southern part of NAFO Division 4R (4Rd) (Table 6).

Consumption of 4T cod by grey seals has increased from 2,800 (SD=1,600) tonnes in 1975 to a peak of 9,400 tonnes (SD=5,000) in 1996 and then has since declined to around 5,700 (SD=3,400) tonnes in 2001 (Table 9; Figure 4). Assuming that only 4T cod are consumed by grey seals in NAFO zone 4Vn during winter, approximately six percent of 4T cod were consumed in this area in 1975. Since then, as outlined above, consumption of 4T cod in 4T increased until 1996, but has since declined. However, consumption of 4T cod in 4Vn during winter appears to have increased and now accounts for about 30% of the total consumption of 4T cod by grey seals. However, data from this area are very limited. The consumption of other species varied from a low of 60 (SD=60) tonnes of Mackerel in 2001 to a high of 9,900 (SD=9,400) tonnes of Winter flounder in 2001 (Table 9; Figures 5,6).

Harp seals consumed an estimated 20 (SD=60) tonnes of Atlantic Cod in 4T in 1970. This increased to 60 (SD=180) tonnes in 2001 using a diet from animals collected from the Magdalen Islands in March and from the St. Lawrence Estuary (Figure 7). Using the same diet, they also consumed an estimated 41,000 (SD=33,000) and 30 (SD=40) tonnes of Capelin and Herring respectively in 2001 (Figure 8; Table 10). Harp seals also spend some time in the northern portion of 4VN. Unfortunately, there is no diet information available from this area, but if the amount of cod is similar to that of harp seals in the northern Gulf of St. Lawrence

(NAFO 4Rabc)(Table 6), then harp seals may have consumed another 700 (SD=100) tonnes in 1970, increasing to 2,100 (SD=400) tonnes in 2001. Snow crab consumption was determined using the complete 4T diet sample, resulting in an estimated consumption of 400 (SD=500) tonnes in 2001 (Table 10; Figure 8). This increases to 1,700 (SD=500) tonnes if only samples collected in the region of the Magdalen Islands are used (Table 10). The 4T diet consisted primarily of animals collected in the St. Lawrence estuary and in the Magdalen Islands during the pupping season in March. This diet was relatively high in capelin owing to the high contribution to the diet from the Estuary samples (Table 5), but it was also relatively high in flatfish and crab which is unusual. To provide a range of possible consumption estimates, a diet from the northern Gulf was also used to estimate cod consumption by harp seals in 4T and in 4VN. The high cod diet assumed that seals in 4T had a diet composition similar to the northern Gulf of St. Lawrence (Division 4Rabc), and that harp seals in 4VN had a diet similar to harp seals from 4Rd. If cod is more important in the diet than indicated by the 4T diet alone, then cod consumption by harp seals could have increased from 8,800 (SD=1,200) in 1970 to 21,700 (SD=3,000) tonnes in 2001 (Table 11, Figure 9).

Data on the size compostion of cod in the grey seal diet are limited to only 14 measurable otoliths (Table 12). Grey seals consumed fish between 10 cm and 55 cm in length. Half of the fish were ≤31 cm in length. Among harp seals almost 90% of the fish consumed were ≤31 cm in length (Figure 10). When converted into biomass 56% of the fish consumed are ≤31 cm in length (Figure 11).

Consumption of 4T Atlantic Cod by grey seals and harp seals combined may be between 19,200 (SD=5,000) and 38,700 (SD=5,800) tonnes. However, it is likely that as much as a half of this consists of fish 31 cm in length or less.

Discussion

The principal objective of this study was to estimate prey consumption by grey and harp seals in NAFO Division 4T. These estimates are based on a considerable number of assumptions about population size, diet composition, spatial distribution, and energy consumption (Hammill and Stenson 2000; Stenson *et al.* 1997). As more information is obtained it is expected that changes will occur in these estimates. Previous work has indicated that pinniped population size was the most important factor affecting fish consumption estimates (Hammill *et al.* 1995, Shelton *et al.* 1997; Stenson *et al.*,1997). The herd of grey seals that whelps on Sable Island, is the largest in the Northwest Atlantic, but population size in this area has not been evaluated since 1997. In this study, we assumed that the population has continued to grow at an annual rate of about 12%. Pup production in the Gulf has declined since 1999, the last time this herd was censused. We assumed that this decline has continued. Changes in trends of population growth or decline of either of these herds have important impact on our estimates of consumption. To reduce some of the uncertainty associated with our estimates of consumption, an updated estimate of current population size is required. In the previous assessment of consumption in 4T, it was assumed that mortality of males was much higher than

females (Mohn and Bowen 1996). However, a more recent study (Manske *et al.* 2002), supports the findings by Mansfield and Beck (1977) that male and female mortality rates are very similar. This results in a Northwest Atlantic grey seal population that is about 25% larger than assumed earlier. We have also assumed that average daily age specific energy requirements of seals are a function of body mass$^{0.75}$ multiplied by constants to account for energy requirements due to activity and growth. We do not vary these constants with season, age or sex class or diet composition. Age-body mass relationships were based on samples collected after reproduction (when body mass is near the annual minimum) and thus underestimate total annual energy requirements. However, we also do not take into account seasonal changes in energy requirements associated with reproduction and moult. Reproduction costs only add about 5% to the total energy requirements of the population (Olesiuk 1993), but our assumption that consumption rates do not change during lactation, breeding and moulting periods (when most adults reduce caloric intake and rely on fat reserves to meet their energetic needs) will lead to overestimating consumption during January and May, and underestimating consumption during February, March and April in grey seals. Among harp seals we would overestimate consumption during March and April, and underestimate consumption in May.

The two variables which show the greatest variability are temporal/spatial changes in distribution and temporal/spatial changes in diet composition. They are also perhaps the two variables for which we have the least information (Shelton *et al.* 1997). This problem becomes more crucial as attempts are made to estimate consumption in smaller, more specific divisions. Satellite telemetry has shown that grey seals can move in and out of the Gulf several times in January, thus moving from 4T, to 4VN and back or moving onto Sable Island in NAFO division 4W. Thus an animal could feed in 4VN, but be sampled in 4T or 4VSW. All of the diet data used in this study were obtained from stomach and intestine contents. This material represents what was consumed in the most recent meal, which limits information to the most recent 36 h period. At most this may provide information on diet composition within 30-50 km of the coast. If seals are feeding on different prey in offshore areas, then this diet would be under-represented in our diet samples. Within the limits of the current data set, we have a large number of recent samples from the Northumberland Strait area, but few cod are found in this area. With the exception of a few stomachs collected from grey seals from the Magdalen Islands in the early 1990s, Information is lacking on prey consumed by grey seals in the central or northern portion of NAFO zone 4T , around the regions of Gaspe and the Magdalen Islands, an area where cod are known to be more abundant. Samples from these areas would result in more even coverage throughout 4T, would minimize the area greater than 50 km from land based sampling sites that are not accessible with our current sampling protocol and would also help to reduce the considerable uncertainty associated with our estimates of fish consumption by grey seals in this area. Approximately 1/3 of the estimated 4T cod consumed by grey seals is consumed in 4VN. However, these estimates are based on 16 samples collected during winter and 90 samples collected during summer. We also assumed that only 4T cod were consumed by harp seals and grey seals in division

4VN. This scenario is unlikely, consequently consumption of 4T cod in this area will be overestimated. Clearly, more sampling is needed from this area.

Harp seals are first seen in 4T in December, and remain in the area until late May. However, diet data in the Gulf portion of 4T are limited to samples from March, when animals feed little. Compared to other areas, this sample also appears to be unusual because of the relative importance of flatfish and snow crab in this diet sample. Sergeant (1991) obtained some diet data during April in the 1960's and 1970's. Different techniques were used to analyse these data, which prevents the material from being incorporated into the current consumption model, but they indicate a higher fraction of herring and cod in the diet which would be expected. Diet data are also lacking for 4VN. Harp seals do occur in the northern part of the area during winter, but no sampling has been completed to date.

In spite of the absence of fishing, 4T cod show limited signs of recovery. There has been a question of whether seals could be having an impact on the recovery of this stock. The consumption of 4T Atlantic cod by grey seals is estimated to be around 5,700 tonnes, with about half of this consumption likely to be fish less than 31 cm long. As outlined above, diet data for some areas of the Gulf, and for 4VN where cod from the southern Gulf of St. Lawrence overwinter are limited and our estimates are based on assumptions concerning changes in population size and the component of 4T cod in the diet consumed in 4VN. Sampling from the central and northwestern portions of 4T and from 4VN are needed to increase our confidence in these estimates. Estimates of cod consumption by harp seals range from 2,200 to 21,700 tonnes depending on assumptions made about harp seal diet composition. The low estimate of cod consumption by harp seals has been estimated using a Magdalen Island and St. Lawrence Estuary diet. This sample likely underestimates cod consumption because cod leave the Gulf during the winter when sampling of seals in both the Estuary and the Magdalen Island area occurred. In the Estuary, capelin are a key prey item for harp seals. However, capelin abundance is much lower in the southern Gulf than in the Estuary, therefore these samples may represent atypical (or represent very local conditions) diets for harp seals in 4T. Owing to the limited diet data for harp seals in 4T, and in 4VN, and an interest in looking at possible upper bounds of consumption of 4T cod by harp seals, we applied a harp seal diet from the Northern Gulf (NAFO Division 4R). Use of this diet indicated that cod consumption by harp seals could be much greater, but until actual harp seal diet data are obtained for the 4VN and Cabot Strait areas during winter, and for eastern 4T during the spring these estimates of consumption can only be considered as hypothetical upper limits.

Combining a consumption of 4T cod by harp seals (2,200-21,700 tonnes) with a consumption of 5,700 tonnes by grey seals, results in a total seal consumption between 7,900 and 27,900 tonnes. This estimate suggests that consumption of 4T cod by seals could be much higher than previously thought. However, improved diet sampling and distribution data are needed for both species, particularly in the case of harp seals, where actual diet data from the study area, outside of the March when harp seals are more likely to be feeding.

In the near term, improvements in our understanding of consumption by grey seals will be achieved by maintaining the data time-series in the southern Gulf, and by augmenting this sampling effort with collections from the Magdalen Islands and the Gaspe. Our understanding of harp seal diets in the southern Gulf is quite poor. Clearly more samples outside of the March period are needed from both 4T and the northern portions of 4VN. Improvements in information on offshore diet and distribution (satellite tagging) of animals are also required. However, significant improvements in evaluating the impact of seals on cod in 4T will likely only be achieved by improving our understanding of the functional relationships between predator-prey. Lawson *et al.* (1998) observed that harp seals off Newfoundland preferentially selected capelin, and Arctic cod over other species irrespective of their local abundance, while they were neutrally selective towards Atlantic cod. Ideally, a selectivity study could be undertaken in the southern Gulf to examine prey selection by grey and harp seals. Further insights might then be obtained by overlapping the spatial distribution the at sea distribution of both pinniped species, with current data on fish distribution and movements.

Acknowledgements

I would like to thank Hugo Bourdages for comments on an earlier version of the manuscript and for identifying an important error in earlier calculations.

References

Beck, C. G., M. O. Hammill and T. G. Smith. 1993a. Seasonal variation in the diet of harp seals (*Phoca groenlandica*) from the Gulf of St. Lawrence and western Hudson Strait. *Can. J. Fish. Aquat. Sci.*, **50** : 1363-1371.

Bowen, W.D. J.W. Lawson and B. Beck. 1993. Seasonal and geographic variation in the species composition and size of prey consumed by grey seals (*Halichoerus grypus*) on the Scotian Shelf. Can. J. Fish. Aquat. Sci. 50 :1768-1778.

Bowen, W. D. 1997. Role of marine mammals in aquatic ecosystems. *Mar. Ecol. Prog. Ser.*, **158** : 267-274.

Chabot, D., G. B. Stenson, and N. B. Cadigan. 1996. Short- and long-term fluctuations in the size and condition of harp seal (*Phoca groenlandica*) in the Northwest Atlantic. *NAFO Sci. Coun. Studies* **26** : 15-32.

Hammill, M. O., M. C. S. Kingsley, G. Beck and T. G. Smith. 1995. Growth and condition in the Northwest Atlantic harp seal. Can. J. Fish. Aquat. Sci. **52** :478-488.

Hammill, M.O., Ryg, M.S., and Mohn, B. 1995. Consumption of cod by the Northwest Atlantic grey seal in Eastern Canada. Pages 337-349 in Whales, seals, fish and man. Edited by A.S. Blix, L. Walløe and Ø. Ultang. Proceedings of the International Symposium on the Biology of Marine Mammals in the North-East Atlantic. 29 November - 1 December 1994. TromsØ, Norway.

Hammill, M.O. and G.B. Stenson. 2000. Estimated prey consumption by harp seals (*Phoca groenlandica*), grey seals (*Halichoerus grypus*), Harbour seals (*Phoca vitulina*) and hooded seals (*Cystophora cristata*). J. Northw. Atl. Fish. Sci. 26 :1-23.

Harwood, J. 1992. Assessing the competitive effects of marine mammal predation on commercial fisheries. *So. Afr. J. Mar. Sci.*, **12** : 689-693.

Harwood, J. and J. P. Croxall. 1988. The assessment of competition between seals and commercial fisheries in the North Sea and the Antarctic. *Mar. Mamm. Sci.*, **4** : 13-33.

Healey, B. and G. Stenson. 2000. Estimating pup production and population size of the Northwest Atlantic harp seal (*Phoca groenlandica*). Northwest Atlantic Fisheries Organization, Scientific Council. NAFO SCR Doc. 00/55.

Kleiber, M. 1975. The Fire of Life : An Introduction to Animal Energetics. (2nd Ed.)

Robert E. Kreiger Publishing Co., New York. 478 p.

Lawson, J. W., J. T. Anderson, E. L. Dalley and G. B. Stenson. 1998a. Selective foraging by harp seals, *Phoca groenlandica*, in nearshore and offshore waters of Newfoundland, 1993 and 1994. *Mar. Ecol. Prog. Ser.* 163 : 1-10.

Mansfield, A.W., and Beck, B. 1977. The grey seal in Eastern Canada. Department of Environment, Fisheries and Marine Service Technical Report 704 : 81 p.

Manske,M., W.T. Stobo and C.J. Schwartz. 2002. Estimation of the age-specific probabilities of first return and annual survival rates for the male grey seal (*Halichoerus grypus*) on Sable Island from capture-recapture data. Marine Mammal Science 18 : 145-166.

Mohn, R. and W. D. Bowen. 1996. Grey seal predation on the Eastern Scotian Shelf : modeling the impact on Atlantic cod. *Can. J. Fish. Aquat. Sci.*, **53** : 2722-2738

Murie, D. J. and D. M. Lavigne. 1991. Food consumption of winter harp seals, *Phoca groenlandica*, in the St. Lawrence estuary, Canada. *Can. J. Zool.*, **69** : 1289-1296.

Olesiuk, P. F. 1993. Annual prey consumption by harbour seals (*Phoca vitulina*) in the Strait of Georgia, British Columbia. *Fisheries Bulletin (Dublin)*, **91** : 491-515.

Ronald, K., K. M. Kiever, F. W. Beamish, and R. Frank. 1984. Energy requirements for maintenance and faecal and urinary losses of the grey seal (*Halichoerus grypus*). *Can. J. Zool.*, **62** : 1101-1105.

SAS INSTITUTE . 1987. SAS/STAT™ Guide for Personal Computers, Version 6 Edition. Cary, North Carolina,. 1028 p.

Sergeant, D. E. 1991. Harp seals, man and ice. *Can. Spec. Publ. Fish. Aquat. Sci.*, **114** : 153 p

Shelton, P. A., W. G. Warren, G. B. Stenson, and J. W. Lawson. 1997. Quantifying some of the major sources of uncertainty associated with estimates of harp seal prey consumption. Part II : Uncertainty in consumption estimates associated with population size, residency, energy requirements and diet. *J. Northw. Atl. Fish. Sci.*, **22** : 303-315.

Stenson, G. B., M. O. Hammill, and J. W. Lawson. 1997. Predation by harp seals in Atlantic Canada : preliminary estimates for Arctic cod, capelin and Atlantic cod. J. Northw. Atl. Fish. Sci. **22** :137-154.

Worthy, G. A. J. 1990. Nutritional energetics for marine mammals : Addendums.

In : *CRC handbook of marine mammal medicine : health, disease and rehabilitation. L.A. Dierauf (ed.). CRC Press, Boca Raton, Florida, p. 489-520.*

Table 1. Parameters used in the Gompertz growth curves to estimate body size in harp, hooded, grey and harbour seals. N = Number of individuals measured.

Species/sex	N	Asymptotic weight (W_∞) (kg)	Weight at t_0 (W_0) (kg)	Growth rate (k_0) (kg/y)	Source
Harp seal-male	967	102.60	34.20	11.27	Chabot *et al.* (1996)
Harp seal-female	800	98.60	30.80	12.30	Chabot *et al.* (1996)
Grey seal-male	95	250.44	48.58	19.50	Hammill (unpub)
Grey seal-female	166	188.21	53.92	12.54	Hammill (unpub)

Table 2. Monthly changes in the distribution (%) of Gulf harp seals in NAFO fishing divisions and sub-divisions. Twenty percent of the total herd remains in the Arctic all year round, 20% of the juveniles and 33% of adults move into the Gulf of St. Lawrence between December 1 and May 30.

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
4R	15	12	0	5	25	10	10	10	10	10	10	15
4S	20	15	20	20	25	45	45	45	45	45	45	20
4T	50	58	70	65	35	40	40	40	40	40	40	50
3PN	0	0	0	0	0	0	0	0	0	0	0	0
4VN	5	5	5	5	5	0	0	0	0	0	0	5
3PS	10	10	5	5	10	5	5	5	5	5	5	10
Total	100	100	100	100	100	100	100	100	100	100	100	100

Table 3. Monthly distribution (proportion) of the Gulf (a) and Sable (b) herds of grey seals in Atlantic Canada.

(a) Gulf

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
4R	0	0	0	0.35	0.45	0.45	0.45	0.45	0.45	0.45	0.01	0.01
4S	0	0	0	0.1	0	0	0	0	0	0	0.1	0
4T Gulf	0.9	0.75	0.6	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.85	0.9
4T Gulf estuary	0	0	0	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0
3Pn	0.01	0.005	0.01	0	0	0	0	0	0	0	0	0.01
4Vn	0.08	0.21	0.35	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.02	0.07
3Ps	0.01	0.005	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
4VsW	0	0.03	0.03	0.01	0	0	0	0	0	0	0	0
Other	0	0	0	0	0	0	0	0	0	0	0	0
	1	1	1	1	1	1	1	1	1	1	1	1

(b) Sable

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
4R	0	0	0	0	0	0	0	0	0	0.01	0.01	0
4S	0	0	0	0.15	0.15	0.26	0.26	0.26	0.26	0.20	0.01	0
4T Gulf	0	0	0.10	0.12	0.12	0.10	0.10	0.10	0.10	0.15	0.20	0
4T Estuary	0	0	0	0	0	0.01	0.01	0.01	0.01	0.01	0.01	0
3PN	0	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0	0
4VN	0.05	0.05	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
3PS	0	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
4VSW	0.95	0.95	0.77	0.60	0.60	0.50	0.50	0.50	0.50	0.50	0.65	0.89
Other	0	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0
Total	1	1	1	1	1	1	1	1	1	1	1	1

Table 4. Seasonal distribution of harp and grey seals in the Gulf of St.Lawrence used in earlier consumption calculations where Q1 is January to March, Q2 is April to June. (a) The distribution of grey seals born on Sable Island and born in the Gulf of St.Lawrence. (b) The distribution of harp seals in the Gulf of St.Lawrence. It is assumed that 33% of the adults and 20% of the juveniles in the NW Atlantic harp seal population are found in the Gulf of St.Lawrence on 1 December. In recent years some harp seals remain in the Gulf (5%) throughout the year. The remaining animals leave 30 May.

(a)

	Gulf				Sable			
NAFO	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
4RS	0.0	45.0	45.0	12.0	0.0	18.7	26	7.6
4T	75.0	45.7	46.0	74.0	0.0	11.7	10	12.
4VSW	2.0	0.0	0.0	0.0	89.0	56.7	50.0	65.0
4X 3PS, other	23.0	9.3	9.0	14.0	11.0	12.9	14.0	15.4
All	100.	100.	100.	100.	100.	100.	100.	100.

(b)

	Q1	Q2	Q3	Q4
4R	0.167	0.350	0.500	0.400
4S	0.267	0.400	0.500	0.500
4T	0.467	0.183	0.000	0.033
3Pn	0.050	0.050	0.000	0.033
4VN	0.050	0.017	0.000	0.033

Table 5. Composition of harp seal diet (% Energy) in NAFO Division 4T.

	Les Escoumins 1983	Les Escoumins 1989	Godbout 1996	Magdalen Islands 1989	Magdalen Islands 1996	Mean	SD
Am. Plaice	0.0	0.0	0.0	0.0	1.9	0.4	0.8
Arctic cod	0.0	0.0	0.01	0.0	0.0	0.0	0.0
Atlantic cod	**0.3**	**0.0**	**0.1**	**0.0**	**0.0**	**0.1**	**0.1**
Herring	0.0	0.0	0.2	0.0	0.0	0.0	0.1
Capelin	86.0	98.5	34.0	0.0	0.2	43.7	46.6
Hake	5.0	0.0	0.0	0.0	0.0	1.0	2.2
Redfish	6.0	0.0	0.0	0.0	0.0	1.2	2.7
Salmonid	0.0	1.5	0.0	0.0	0.0	0.3	0.7
Sand lance	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Sculpin	0.0	0.0	0.0	4.8	0.0	1.0	2.1
Smelt	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Yellow tail flounder	0.0	0.0	0.0	56.3	0.0	11.3	25.2
Windowpane	0.0	0.0	0.0	12.6	0.0	2.5	5.6
Stichaeidae	0.0	0.0	0.0	0.0	32.1	6.4	14.4
Other fish	2.6	0.0	0.3	2.8	22.3	5.6	9.4
Euphausiids	0.0	0.0	38.6	0.0	7.0	9.1	16.8
Snow crab	**0.0**	**0.0**	**0.0**	**1.2**	**0.3**	**0.3**	**0.5**
Other invert	0.0	0.0	26.8	22.3	36.2	17.3	16.4
Total	100.0	100.0	100.0	100.0	100.0	100.0	
Mean Energy (kj/g)	9.00	6.21	5.14	4.98	5.01	6.07	1.72
# of samples	25	9	35	62	17		

Table 6. Diet composition of harp seals collected off the west coast of Newfoundland and Quebec Lower North Shore. Diet samples were bootstrapped 1000 times to determine mean and SD. Winter is defined as October to March and Summer is defined as April to September. The North diet ($4R_{abc}$) is the Low cod diet used in this study. The South ($4R_{d}$ diet is the high cod diet).

Division	North (Low cod) 4Rwinter		North (Low cod) 4Rsummer,		South (High cod) 4Rwinter		South (High cod) 4Rsummer		Winter 4S	
Species	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD
Am. Plaice	0.0	0.0	1.0	0.9	0.0	0.0	2.2	1.8		
Amphipod	1.1	1.1	0.2	0.1	0.0	0.0	0.4	0.3		
Arctic Cod	0.2	0.2	0.0	0.0	6.1	2.9	0.1	0.1	0.11	0.4
Atl. Cod	**3.5**	**1.3**	**10.9**	**2.5**	**37.2**	**8.3**	**20.3**	**4.3**	**6.0**	**13.5**
Atl. Herring	**25.7**	**3.8**	**17.5**	**3.1**	**20.8**	**10.6**	**11.4**	**3.9**	**1.6**	**4.0**
Capelin	**50.0**	**4.4**	**31.9**	**4.5**	**2.3**	**1.3**	**22.7**	**5.3**	**27.2**	**36.9**
Euphausiid	0.0	0.0	0.2	0.1	0.0	0.0	0.0	0.0		
Gadoid sp.	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0		
Gadus sp.	0.0	0.0	0.2	0.1	0.1	0.1	0.1	0.1	19.6	29.2
Greenland Halibut	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0		
Lumpfish	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
Mysid	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
Other Fish	0.7	0.3	3.0	1.2	1.2	0.5	2.6	1.8	13.4	
Other Invert	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	1.3	
Pleuronectidae	2.0	1.2	16.6	5.1	4.7	2.0	6.2	4.8		
Redfish sp.	0.0	0.0	3.9	2.2	24.7	5.9	8.1	4.5		
Rock Cod	0.3	0.3	0.7	0.3	0.0	0.0	0.0	0.0		
Salmon	0.0	0.0	0.3	0.3	0.0	0.0	0.0	0.0		
Sand Lance	7.5	1.9	11.2	2.8	0.5	0.4	22.4	5.6	30.7	34.5
Sculpin	1.0	0.9	0.1	0.1	0.0	0.0	0.0	0.0		
Shrimp	7.2	2.2	0.8	0.4	0.1	0.1	1.0	0.6		
Smelt	0.3	0.2	0.0	0.0	1.2	0.8	0.0	0.0		
Squid	0.0	0.0	0.1	0.1	0.0	0.0	0.2	0.1		
White Hake	0.0	0.0	1.1	1.1	0.8	0.5	2.2	2.2		
N	93		353		123		215		25	

Table 7. Diet composition (% energy) of grey seals in 4T. Am=Amet Island (Northumberland Strait), Mi=Miramichi River area, CB=west Cape Breton Island near Margaree Island.

	I. de M. 1992	Amet 1994	Amet 1995	Amet 1997	Am/Mi 1998	Am/Mi/ CB 1999	Am/Mi/ CB 2000
Cod	**17.9**	**0.1**	**0.0**	**0.0**	**0.0**	**12.3**	**0.7**
Herring	12.8	1.4	0.0	0.98	20.6	0.2	2.8
Capelin	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mackerel	0.0	0.0	0.0	0.0	0.0	1.4	0.2
Lycod	3.4	0.0	0.0	0.0	0.0	0.0	0.0
Sandlance	0.2	0.0	0.0	0.0	29.4	6.4	4.0
Yt. flounder	0.8	1.6	4.3	0.54	0.0	1.0	0.0
Winter flounder	0.0	73.8	84.0	49.95	3.71	2.9	0.6
Plaice	52.1	0.0	0.0	0.0	0.0	2.6	0.0
Smelt	0.0	0.0	0.0	0.08	0.1	0.0	0.0
Cunner	0.0	5.0	5.6	9.55	41.9	3.0	76.0
Salmon	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ocean pout	0.0	0.2	0.0	0.0	0.0	0.0	0.0
Flatfish	0.0	0.6	1.2	1.30	0.6	2.5	2.6
Wh hake	0.0	0.0	0.0	0.01	1.7	58.1	6.2
Other fish	12.7	17.2	4.8	37.56	2.0	9.6	6.9
Mean energy (kjoules/g)	4.4	3.8	3.8	4.20	5.9	5.5	6.3
# samples	6	12	4	14	19	70	31

Table 8. Bootstrapped diet for NAFO Division 4T expressed as % energy, and used to estimate grey seal consumption. This bootstrap used 170 animals collected between 1997 and 2000. The small samples collected in 1992, 1994 and 1995 (N=16) were not included. Data for NAFO Division 4VN are from Bowen *et al.* (1993).

	Division 4T		Division 4VN
	Mean	SD	
White Hake	20.3	2.3	
Sand Lance	15.3	2.4	
Unidentified	14.1	2.2	
Herring	9.9	1.9	
Winter Flounder	9.5	1.6	
Pleuronectidae sp	7.5	1.5	
Cunner	6.8	1.5	
Cod	5.8	1.1	10
Mackerel	1.8	0.9	
Sculpin	1.8	0.7	
Peprilus sp	1.5	0.4	
Cryptacanthodes sp	1.2	0.6	
Cottidae	1.0	0.3	
Windowpane	1.0	0.3	
Plaice	0.9	0.4	
Smelt	0.4	0.2	
Y.-T Flounder	0.3	0.3	
Stichaeidae sp	0.3	0.2	
Carid	0.1	0.0	
Zoarcidae	0.1	0.0	
Sculpin	0.1	0.1	
Amphipods	0.1	0.0	
Ocean Pout	0.1	0.0	
Snakeblenny	0.0	0.0	
Decapods	0.0	0.0	
Crustacea sp	0.0	0.0	
Eelpout	0.0	0.0	

Table 9. Consumption ('00s tonnes) of cod, herring, sand lance, mackerel, white hake and winter flounder by grey seals in 4T.

Year	4T Cod : In 4T		4T Cod : In 4VN		4T Herring		4T Sand Lance		4T Mackerel		4T White Hake		4T Winter Flounder	
	Mn	SD	Mn	SD	Mn	SD	Mn	SD	Mn	SD	Mn	SD	Mn	SD
1975	28	16	2	1	23	8	9	6	0.4	0.3	13	10	66	48
1976	29	16	3	1	23	8	9	6	0.4	0.3	13	10	68	49
1977	31	17	3	1	24	9	9	6	0.4	0.3	14	10	71	52
1978	32	18	3	1	25	9	10	7	0.5	0.3	15	11	74	54
1979	34	19	3	1	27	10	10	7	0.5	0.4	15	11	78	57
1980	36	20	3	1	28	11	11	7	0.5	0.4	16	12	83	60
1981	37	22	3	1	30	11	11	8	0.5	0.4	17	13	87	63
1982	39	22	4	1	31	12	12	8	0.6	0.4	18	13	91	66
1983	40	23	4	1	32	12	12	8	0.6	0.4	18	14	93	68
1984	41	24	4	1	33	12	12	9	0.6	0.4	19	14	96	71
1985	44	25	4	1	35	13	13	9	0.6	0.5	20	15	102	75
1986	47	27	5	1	37	14	14	10	0.7	0.5	21	16	108	80
1987	50	29	5	1	40	15	15	10	0.7	0.5	23	17	116	85
1988	53	31	6	2	42	16	16	11	0.8	0.6	24	18	124	92
1989	57	33	6	2	45	17	17	12	0.8	0.6	26	20	132	98
1990	60	36	7	2	48	19	18	13	0.9	0.7	28	21	141	104
1991	64	38	7	2	51	20	19	14	0.9	0.7	30	22	150	111
1992	69	41	8	2	55	22	21	15	1.0	0.7	32	24	160	120
1993	73	44	9	2	58	23	22	16	1.1	0.8	34	26	171	127
1994	77	46	10	3	62	25	23	17	1.1	0.8	36	27	180	135
1995	81	49	10	3	64	26	24	17	1.2	0.9	37	28	188	141
1996	82	50	11	3	66	27	25	18	1.2	0.9	38	29	192	145
1997	76	47	12	3	60	26	23	17	1.1	0.8	35	27	176	135
1998	67	43	12	4	53	24	20	15	1.0	0.8	31	24	155	122
1999	59	39	13	4	47	24	18	14	0.9	0.7	27	22	138	112
2000	50	36	14	4	40	22	15	13	0.7	0.6	23	20	118	103
2001	42	33	15	4	34	21	13	12	0.6	0.6	19	18	99	94

Table 10. Consumption ('00s tonnes) of Capelin, 4T Cod, Herring and snow crab by Harp seals using diet data from The St. Lawrence Estuary and Gulf of St. Lawrence, and a northern Gulf low cod diet for NAFO Division 4VN.

Year	4T Capelin		4T Cod		4T Herring		4T Cod in 4VN		Snow Crab		Hi_Snow Crab	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1975	170	140	.20	.80	.10	.20	8	2	2	2	7	2
1976	170	140	.20	.80	.10	.20	9	2	2	2	7	2
1977	180	140	.20	.80	.10	.20	9	2	2	2	7	2
1978	190	150	.30	.80	.10	.20	9	2	2	2	8	2
1979	190	160	.30	.90	.10	.20	10	2	2	3	8	2
1980	200	160	.30	.90	.10	.20	10	2	2	3	8	3
1981	210	170	.30	.90	.10	.20	10	2	2	3	9	3
1982	220	170	.30	.10	.10	.20	11	2	2	3	9	3
1983	220	180	.30	.10	.10	.20	11	2	2	3	9	3
1984	240	190	.30	.11	.10	.30	12	2	2	3	10	3
1985	250	200	.30	.11	.20	.30	13	3	3	3	10	3
1986	270	220	.40	.12	.20	.30	13	3	3	4	11	3
1987	290	230	.40	.13	.20	.30	14	3	3	4	12	4
1988	300	240	.40	.13	.20	.30	15	3	3	4	12	4
1989	310	250	.40	.14	.20	.30	15	3	3	4	13	4
1990	320	260	.40	.14	.20	.30	16	3	3	4	13	4
1991	330	270	.50	.15	.20	.40	16	3	3	4	14	4
1992	350	280	.50	.16	.20	.40	17	4	4	5	14	4
1993	360	290	.50	.16	.20	.40	18	4	4	5	15	5
1994	380	310	.50	.17	.20	.40	19	4	4	5	16	5
1995	390	320	.50	.18	.20	.40	20	4	4	5	16	5
1996	410	330	.60	.18	.30	.40	20	4	4	5	17	5
1997	410	330	.60	.18	.30	.40	20	4	4	5	17	5
1998	410	330	.60	.18	.30	.40	20	4	4	5	17	5
1999	410	330	.60	.18	.30	.40	20	4	4	5	17	5
2000	410	330	.60	.18	.30	.40	21	4	4	5	17	5
2001	410	330	.60	.18	.30	.40	21	4	4	5	17	5

Table 11. Estimate consumption (tonnes) of 4T cod by harp seals, using a low, medium and high composition of cod in the diet.

Year	Low Cod		Medium Cod		High Cod	
	Mean	SD	Mean	SD	Mean	SD
1975	820	200	5200	900	8800	1200
1976	920	200	5500	900	9200	1200
1977	920	200	5600	1000	9400	1300
1978	930	200	5800	1000	9800	1300
1979	1030	200	6100	1100	10200	1400
1980	1030	200	6300	1100	10600	1500
1981	1030	200	6500	1100	11000	1500
1982	1130	200	6800	1200	11300	1600
1983	1130	200	7000	1200	11700	1600
1984	1230	200	7400	1300	12400	1700
1985	1330	300	8000	1400	13300	1800
1986	1340	300	8400	1500	14200	2000
1987	1440	300	8900	1600	15000	2100
1988	1540	300	9300	1600	15600	2100
1989	1540	300	9600	1700	16100	2300
1990	1640	300	10000	1700	16700	2300
1991	1650	300	10400	1800	17500	2400
1992	1750	400	10900	1900	18300	2500
1993	1850	400	11400	2000	19100	2600
1994	1950	400	11900	2100	19900	2800
1995	2050	400	12400	2200	20700	2900
1996	2060	400	12800	2200	21500	3000
1997	2060	400	12800	2200	21500	3000
1998	2060	400	12900	2300	21700	3000
1999	2060	400	12900	2300	21700	3000
2000	2160	400	13000	2300	21700	3000
2001	2160	400	13000	2300	21700	3000

Table 12 . Size Class length of cod consumed by grey seals collected in the southern Gulf of St. Lawrence.

Class	Number of Fish	Cumulative Total	Cumulative Percent
7			
10	2	2	14
13		2	14
16	1	3	21
19		3	21
22	1	4	29
25		4	29
28	1	5	36
31	2	7	50
34	1	8	57
37	1	9	64
40	1	10	71
43		10	71
46	1	11	79
49	1	12	86
52	1	13	93
55	1	14	100

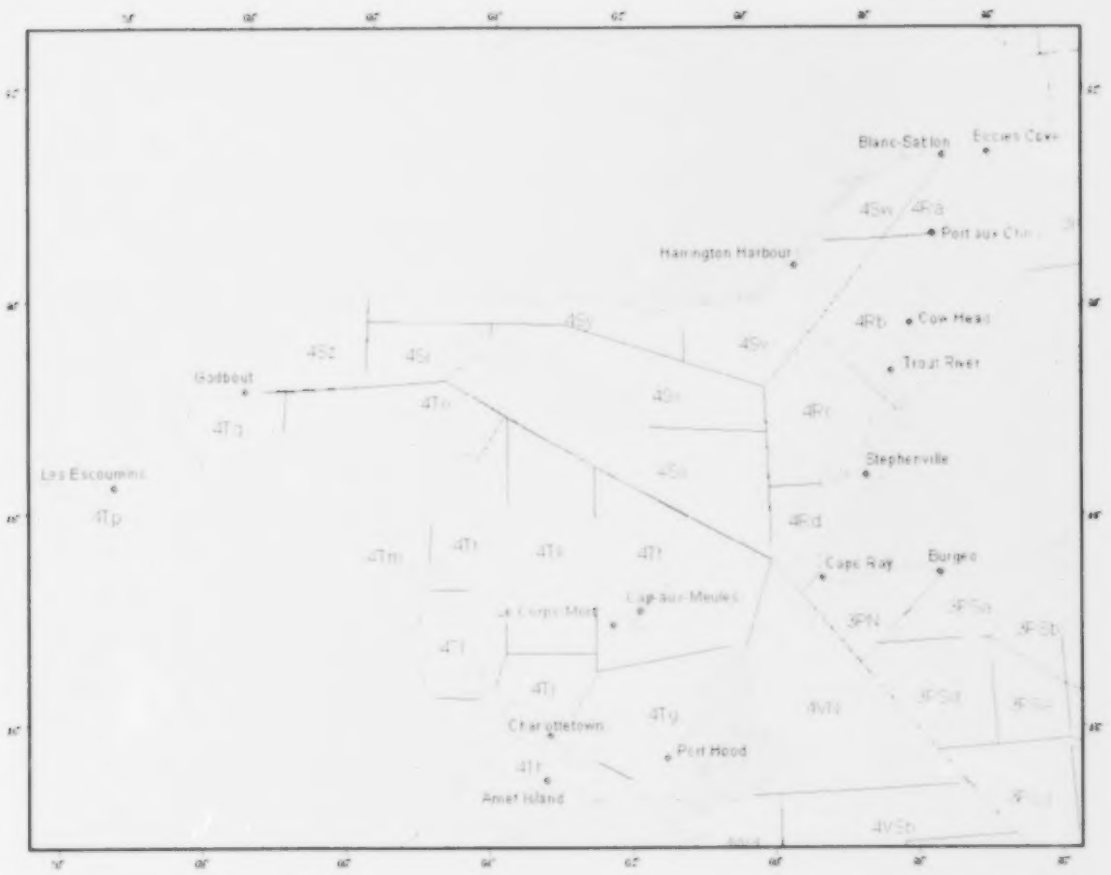

Figure 1. NAFO divisions, sub-divisions and unit areas in the Gulf of St. Lawrence. Place names show sampling locations for harp and grey seals. The shaded area shows the foraging limits likely sampled using stomach and intestine contents.

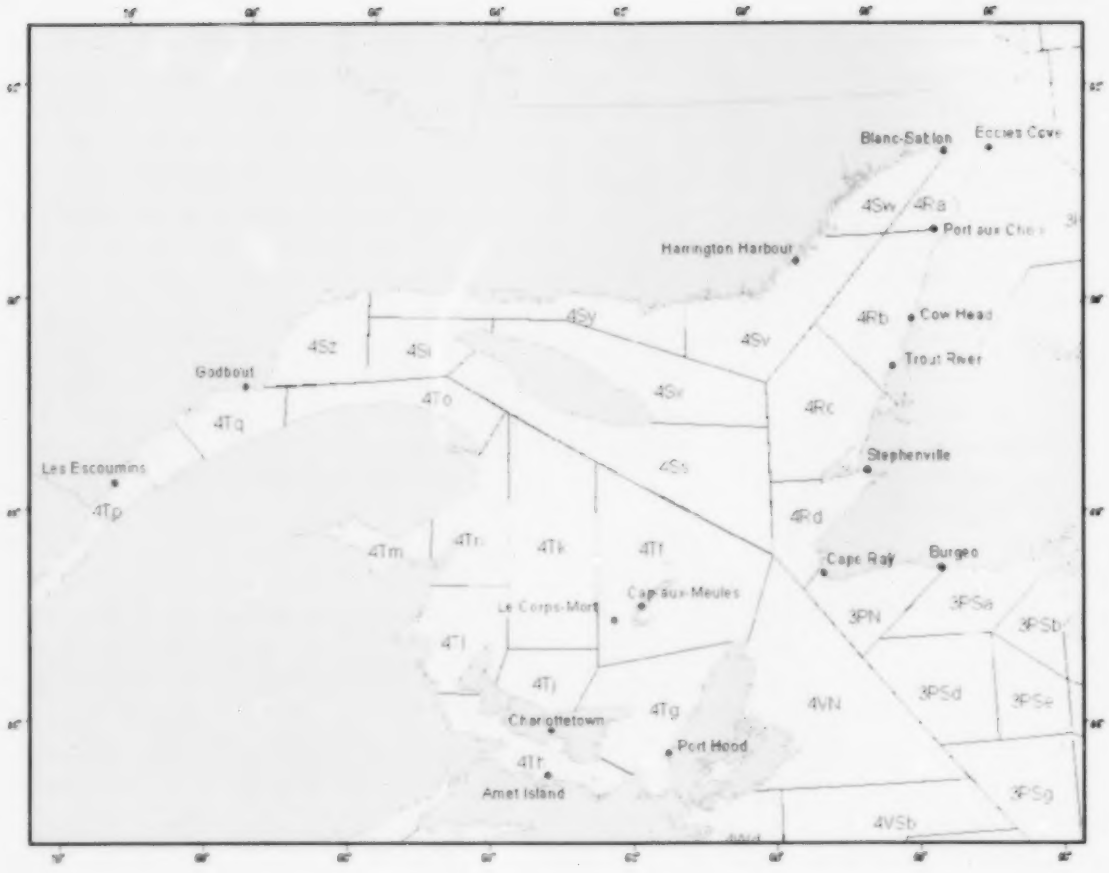

Figure 1. NAFO divisions, sub-divisions and unit areas in the Gulf of St. Lawrence. Place names show sampling locations for harp and grey seals. The shaded area shows the foraging limits likely sampled using stomach and intestine contents.

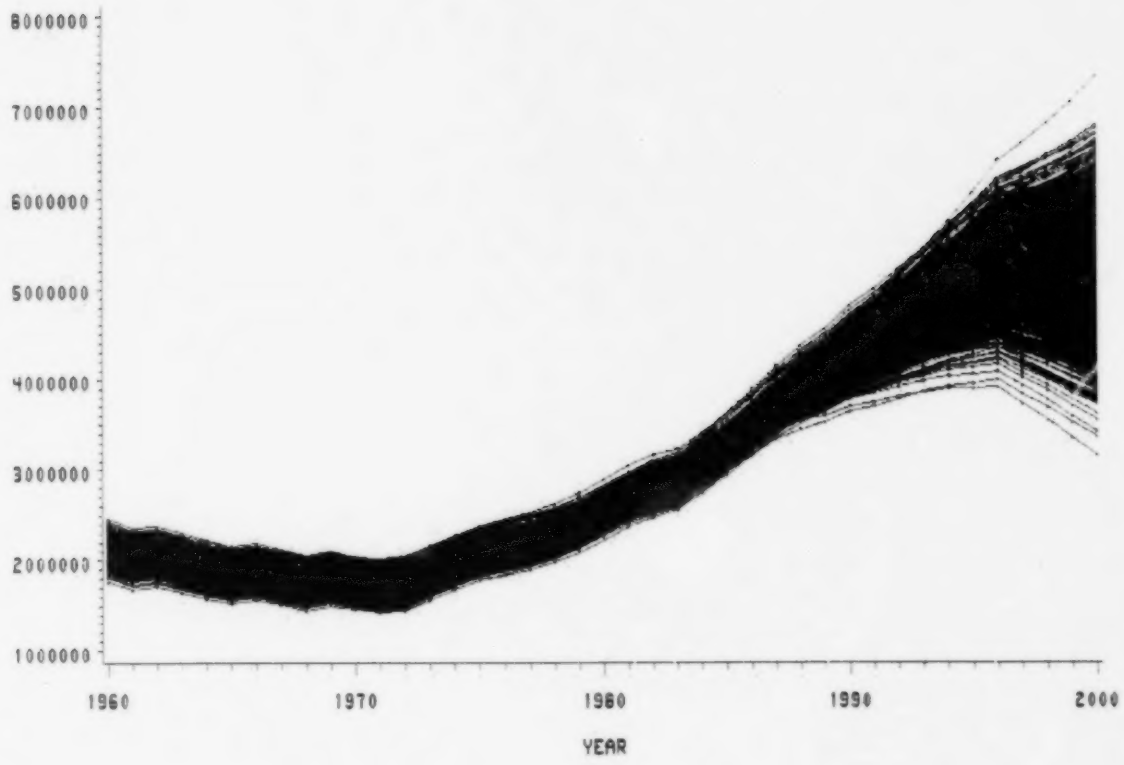

Figure 2. Abundance of Northwest Atlantic harp seals in Atlantic Canada.

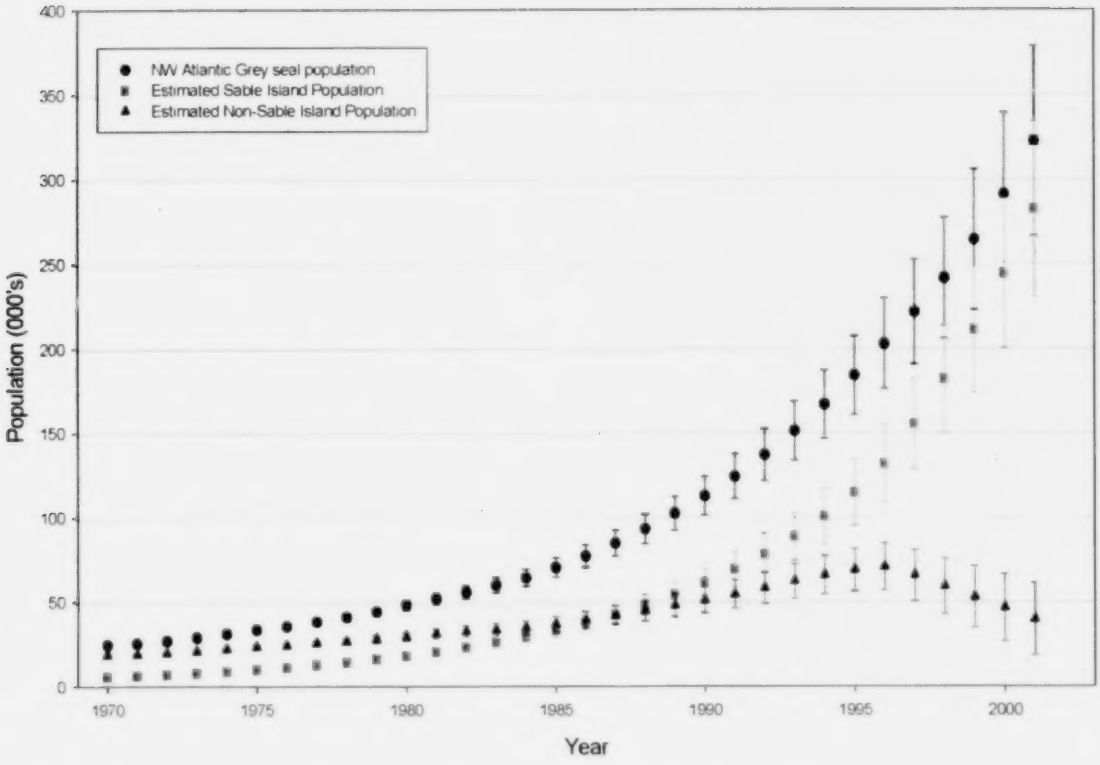

Figure 3. Abundance of Atlantic grey seals from 1970 to 2000. The vertical bar represents ± 1SE.

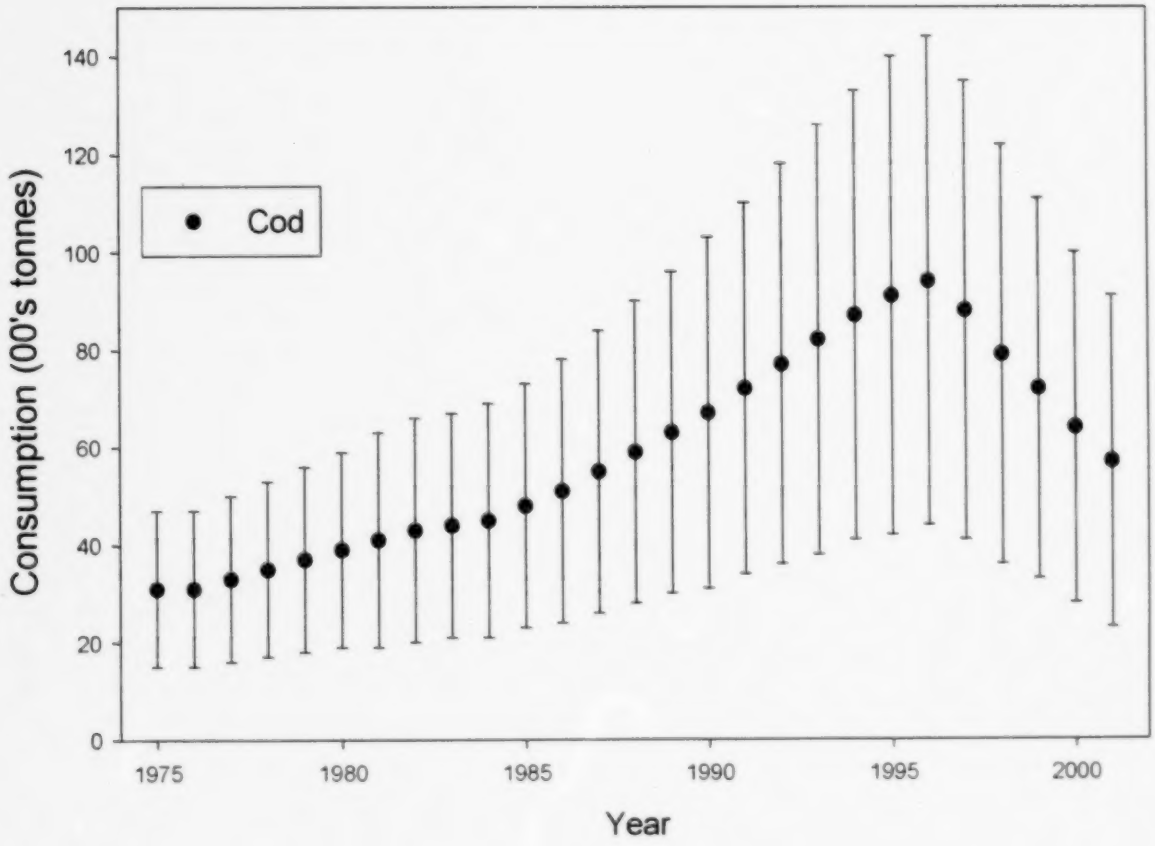

Figure 4. Estimated consumption of 4T Atlantic cod in 4T and in 4VN during winter by grey seals between 1984 and 2001. The vertical bar represents ± 1SE

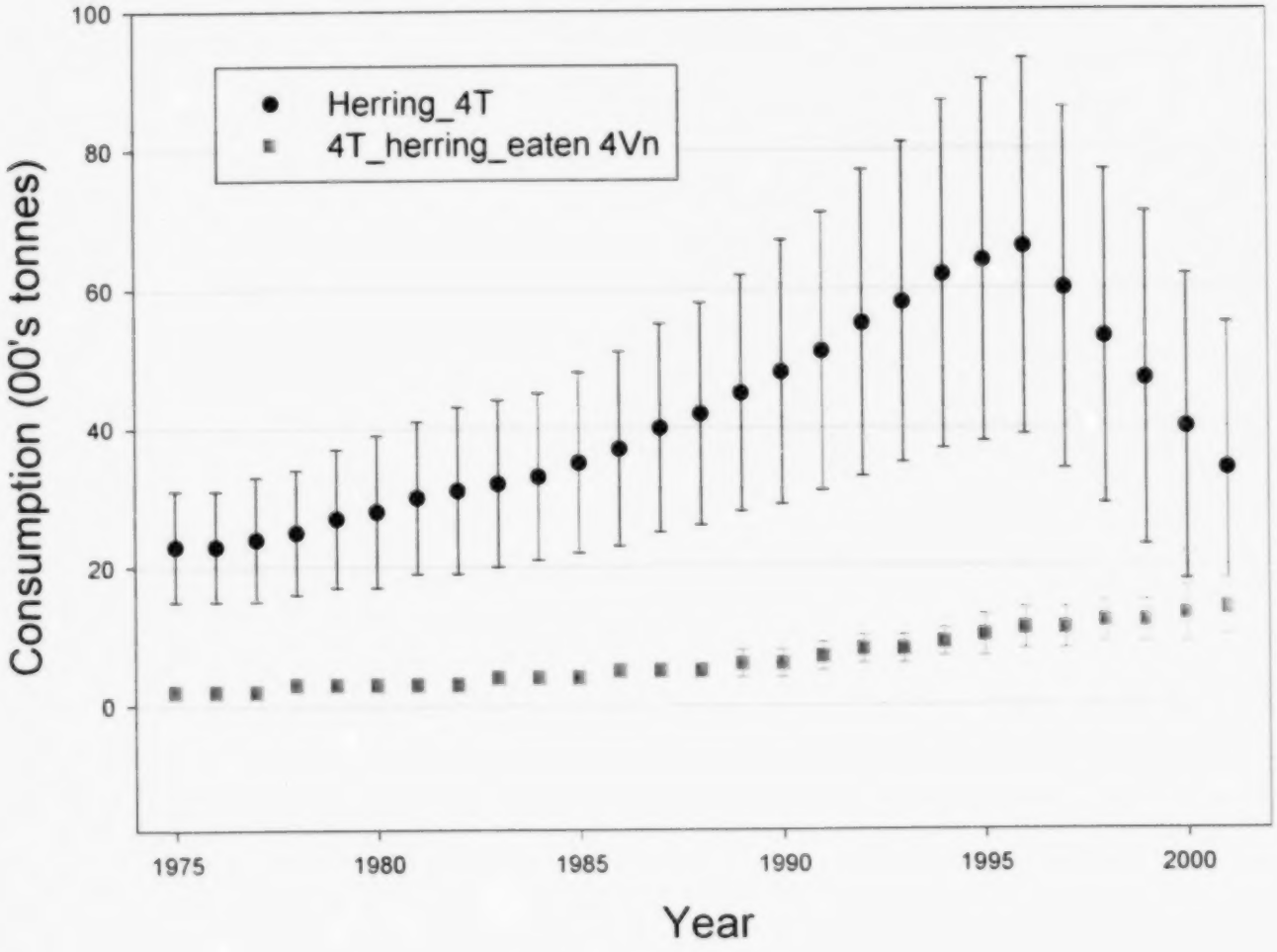

Figure 5. Estimated consumption by grey seals of 4T Atlantic herring in 4T and during winter in 4VN. The vertical bar represents ± 1SE.

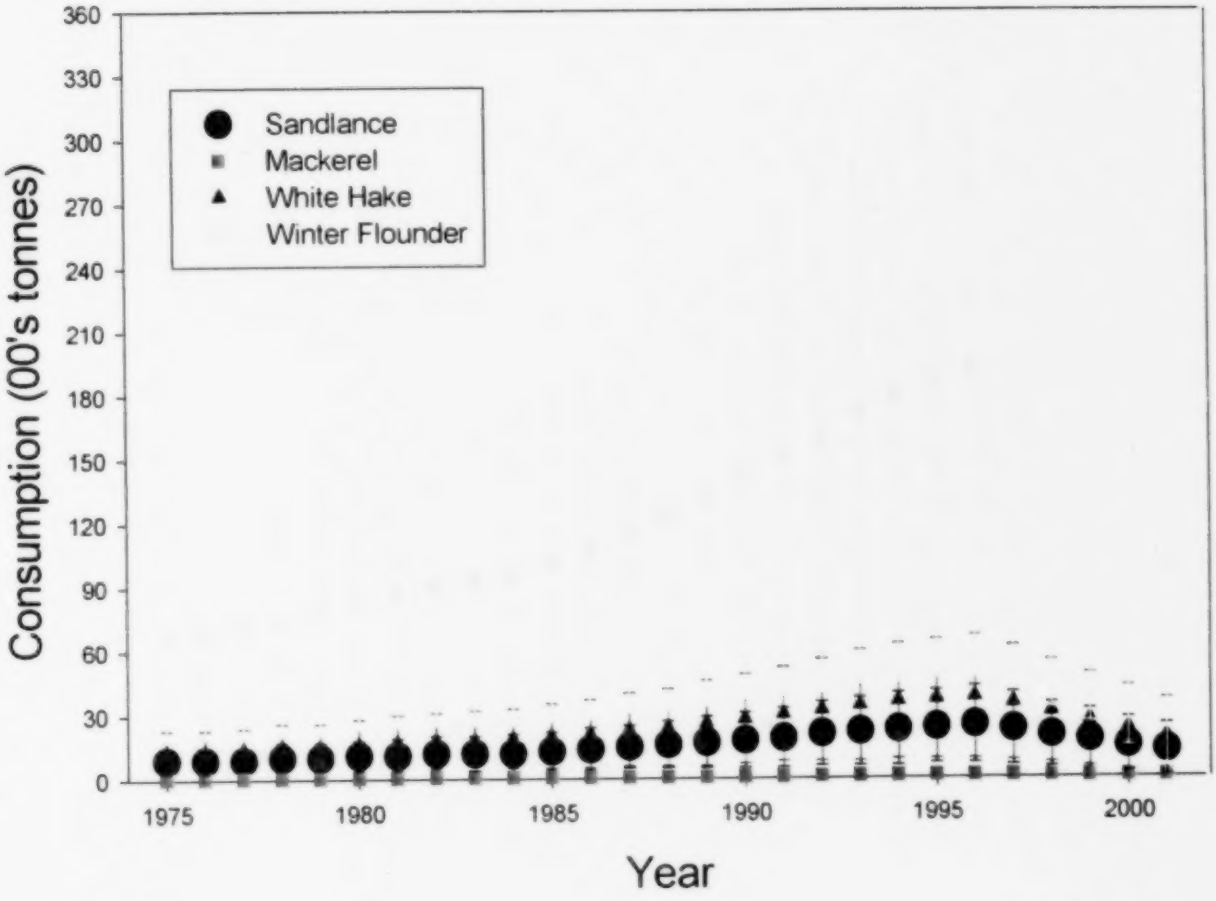

Figure 6. Estimated consumption (tonnes) Sand Lance, Mackerel, and Winter Flounder by grey seals in 4T. The vertical bars represent ± 1SE.

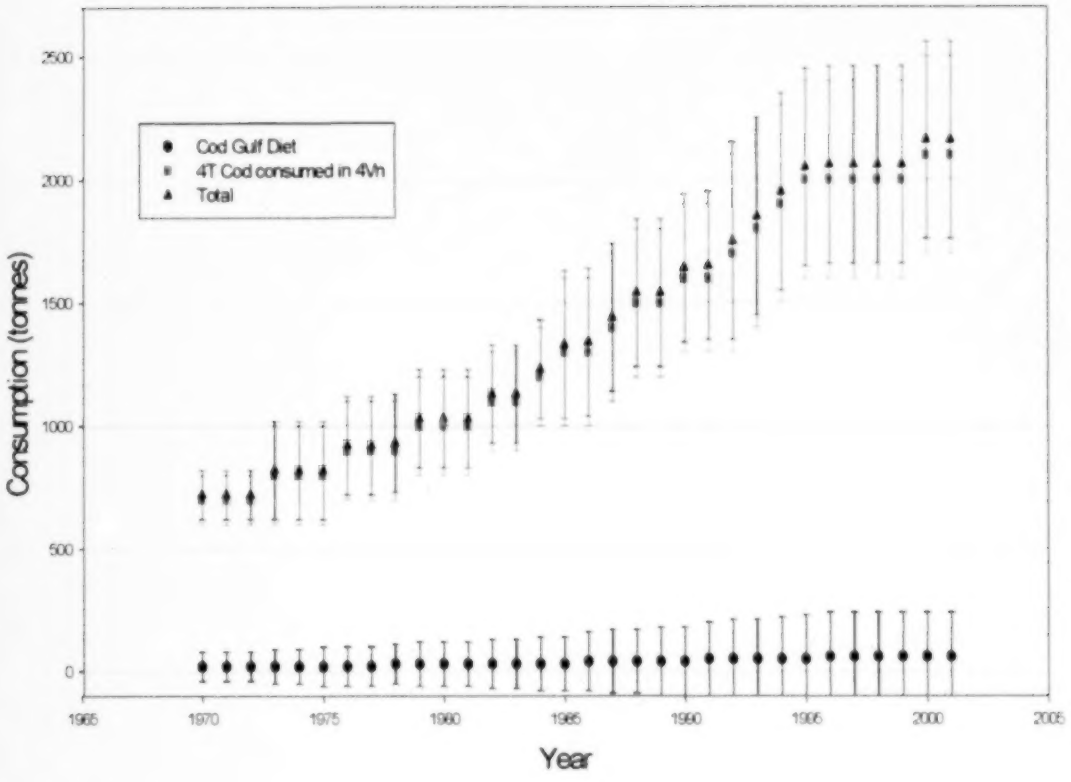

Figure 7. Consumption of 4T cod by harp seals in the Gulf using a Gulf and Estuary diet and in 4VN using a northern Gulf Low cod diet. The vertical bar represents ± 1SE.

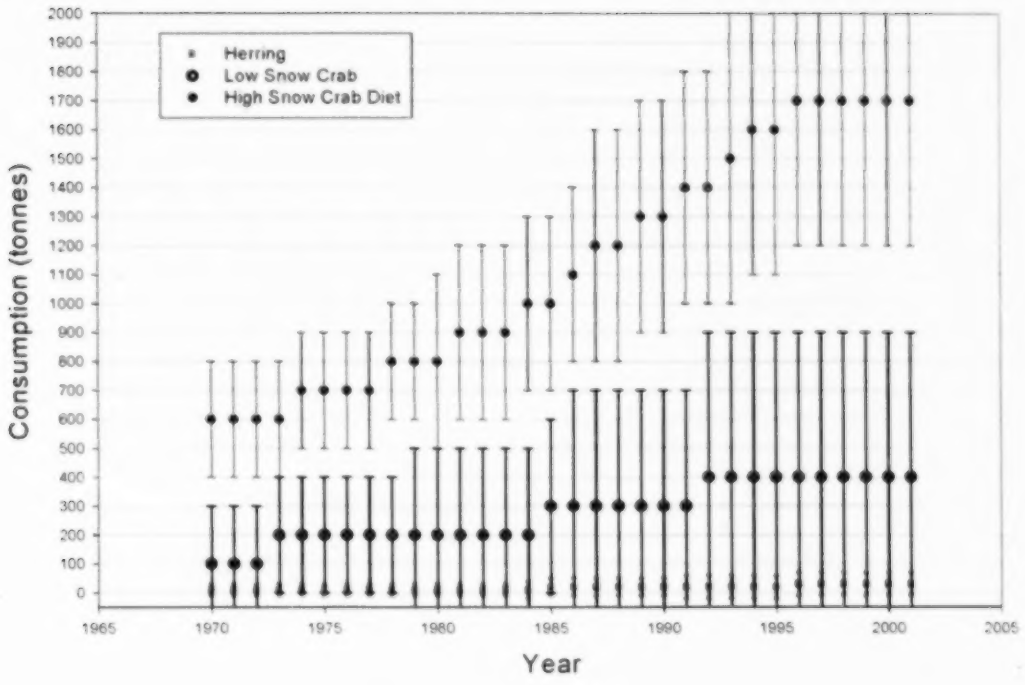

Figure 8. Consumption of 4T snow crab and herring by harp seals using a 4T estuary and 4T Gulf diet combined. The vertical bar represents ± 1SE.

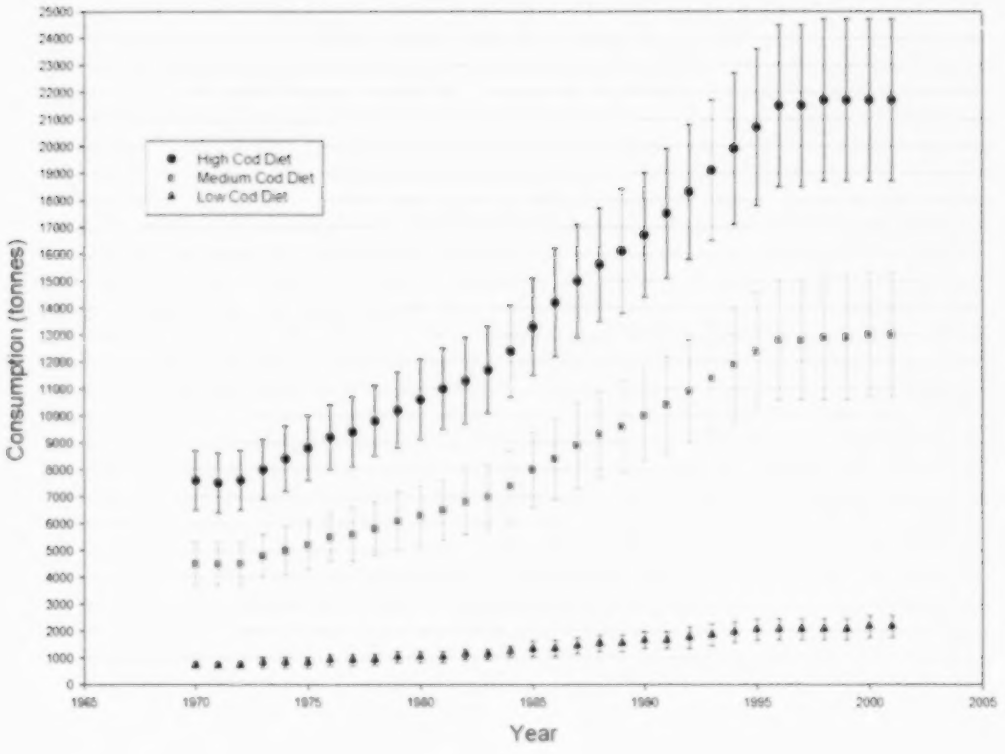

Figure 9. Consumption of 4T cod by harp seals including consumption of wintering cod in 4VN, assuming a low, medium and high cod component in the diet. The vertical bar represents ± 1SE.

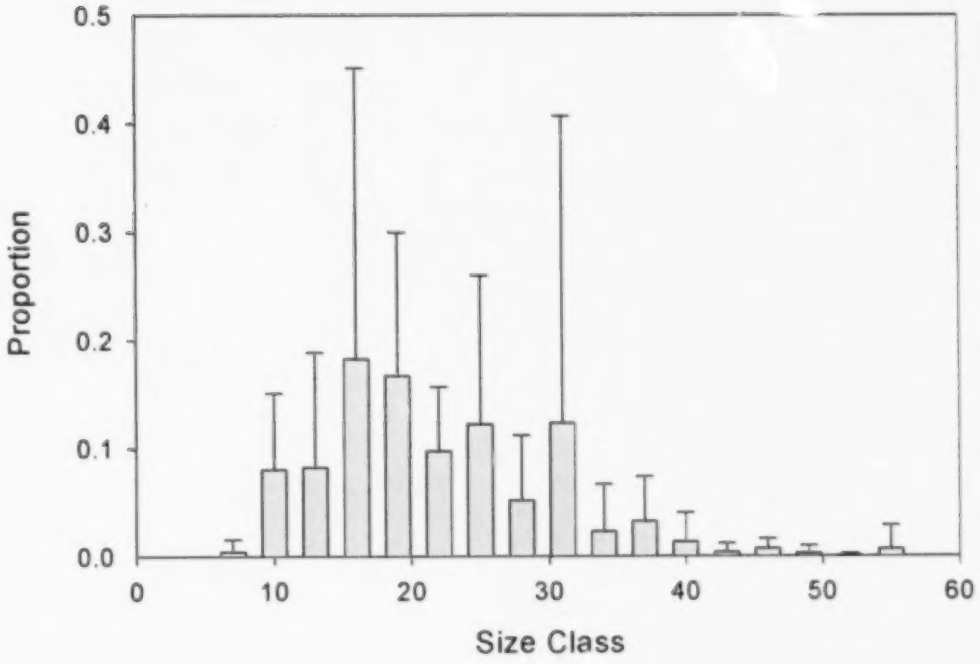

Figure 10. Reconstructed length (cm) frequency distribution of cod found in harp seal stomachs collected in NAFO Division 4R and sub-Division 3PN. The vertical bar represents + 1SE.

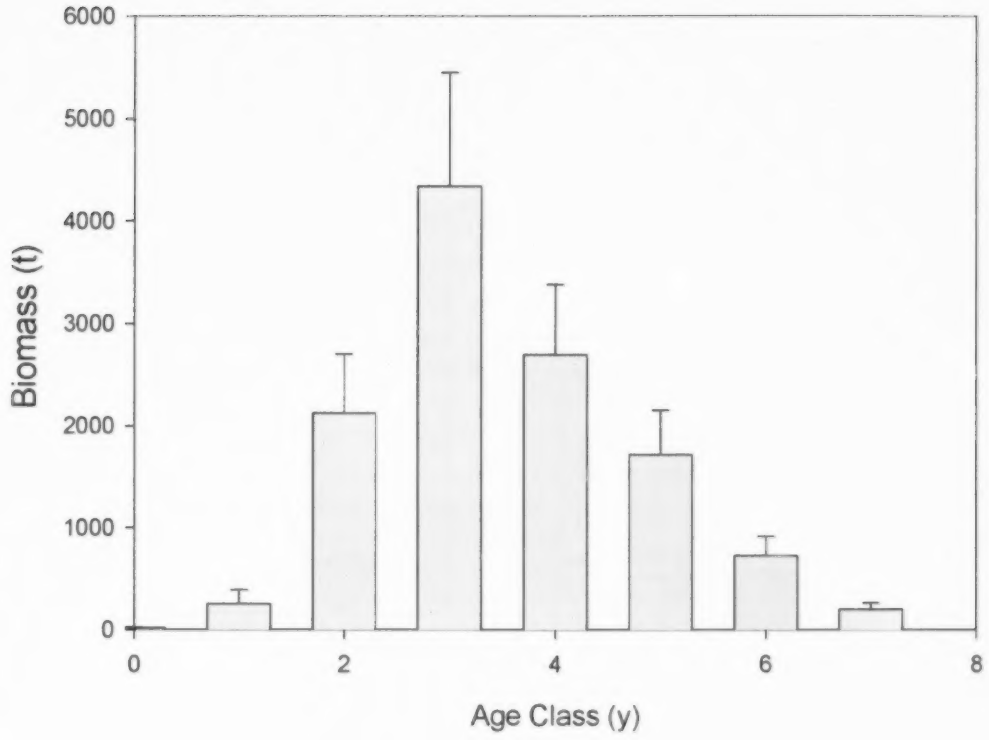

Figure 11. Estimated biomass (t) by age class of cod consumed by harp seals in 2001 in NAFO Division 4R. Age 3 fish are primarily <31 cm in 4R, age 4 is <40cm. The vertical bar represents + 1SE.